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Tillage Effects on the Distribution of Soil Organic Carbon and Nitrogen in Particle-Size Fractions

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Abstract

The non-labile soil organic matter pool associated with clay particles is a vital reservoir for long-term C sequestration. Particle-size fraction concentrations of C and N were determined from the 0- to- 10-cm soil depth in long-term experiments under continuous no-tillage (NT) and conventional tillage (CT) in a Wickham sandy loam (fine-loamy, mixed, semi-active, thermic Typic Hapludult), Delanco fine-sandy loam (fine-loamy, mixed, mesic, Aquic Hapludult), and Wedowee sandy clay loam (fine, kaolinitic, thermic Typic Kanhapludult) in North Carolina Coastal Plain (9 yr), Mountain (14 yr), and Piedmont (24 yr) locations, respectively. Significant treatment effects were most evident in the Piedmont location; where the C concentrations (expressed as g C kg^{-1} fraction) under NT and moldboard plow (MBP) were, respectively, 29.4 and 17.4 in fine clay; and 18.1 and 10.3 in silt + coarse clay fractions. The corresponding N concentrations were, respectively, 2.9 and 2.2 g in fine clay under NT, and 1.7 and 1.4 in silt + coarse clay under MBP. Erosive forces likely caused significant C losses in particle-size fractions under MBP relative to NT over 24 yr in the Piedmont; whereas 9- and 14-yr tillage systems in the Coastal plain and Mountain, respectively, resulted in non-significant differences between CT and NT. The results demonstrate that a given tillage system's duration can be a factor determining particle-size fraction C sequestration in the soil depth studied, and that NT can potentially increase C sequestration by increasing the C content associated with fine clay.

Introduction

Tillage operations result in increased contact of incorporated organic matter with the mineral soil particles (Balesdent et al., 2000). The non-labile pool associated with clay particles is an important reservoir for long-term C sequestration (Kiem et al., 2002). Therefore, particle-size fractionation has been used to examine the response of organic C and N dynamics to the impacts of management practices (Tiessen and Stewart, 1983). The objectives of this study were to compare the distribution of particle-size fractions and dynamics of organic C and N in fine and silt+coarse clay fractions in three long-term experiments under diverse tillage systems in the three physiographic regions of North Carolina. It was hypothesized that fine clay, relative to silt+coarse clay, comprises a smaller proportion of bulk soil but sequesters more C, irrespective of tillage system; and that tillage decreases organic C and N contents in both fractions.

Methods

Study sites included three research stations in North Carolina's three physiographic regions (Fig. 1):
Center for Environmental Farming Systems (CEFS) 9 yr.; Coastal Plain physiographic region (topography: flat to rolling).
Mountain Horticultural Crops Research Station (MHCRS) 14 yr.; Mountain physiographic region (topography: rugged area of mountains with depressions in between; steep ridges and valleys).
Upper Piedmont Research Station (UPRS) 24 yr.; Piedmont physiographic region (topography: rolling and ridgy to hilly).

Experiment designs: RCB; with 3 reps at CEFS; and 4 reps at MHCRS and UPRS.

Treatments: four at CEFS: conventional tillage (CT), no-till (NT), organic amended CT (CTO), and forest regrowth or successional (S); five at MHCRS: synthetic amended CT (CTS) and NT (NTS), organic amended CT (CTO) and NT (NTO), and control CT system receiving no inputs (CT); three at UPRS: moldboard plow/disk (MBP), spring chisel plow (SCP), and no-till (NT).

Sampling: Samples were taken from around previously geo-referenced points at CEFS and within plant rows from 3 to 6 randomly assigned points at MHCRS and UPRS. Three samples were taken, each from the 0- to 10-cm soil depth, around each point in each replication and composited; gently hand-crushed; sieved using 8- and 4-mm aperture sieves; and divided into two portions (one for aggregate and particle-size fractionation and the other for air-drying and determination of physico-chemical properties).

Aggregate fractionation: Yoder (1936) wet sieving method as modified by Haynes (1993).
Particle-size fractionation (separating silt + clay [< 0.053 mm] into fine clay [< 0.0002-mm] and silt + coarse clay [0.053-0.0002-mm]: Modified methods of Laird et al. (1991, 1994).

Total C (TOC) and N (TON): direct combustion in a Perkin–Elmer 2400 CHN analyzer.

Statistical analysis: PROC MIXED was used for analysis of variance and mean separation (SAS Inst., Cary, NC); hypotheses were tested at $p < 0.05$. Table 1 describes tillage systems and selected properties of the soils.

Results and Discussion

Significant treatment effects were evident mainly in the Piedmont location only where:
- Silt + coarse clay proportions were 6 to 12X greater than fine clay (Fig. 2)
- 2X more C was sequestered by fine than by silt + coarse clay under NT or MBP (Fig. 3); and
- C and N were 2X greater under NT than MBP in fine or silt + coarse clay (Figs. 3 and 4)

During SOM decomposition, C transfer is from coarse to fine fractions (Guggenberger et al., 1994), suggesting that organic C binding is more effective in fine than silt + coarse clay.

Organic C associated with fine clay plays greater role in SOM stabilization than that associated with silt + coarse clay (Christensen, 2001).

Management practices do not impact binding agents in the clay range (Stott et al., 1999). Tillage and erosion over 24 yrs resulted in increased clay, but decreased organic C content under MBP compared to NT.

Table 1. Tillage systems and selected chemical and physical properties

System†	pH	CEC‡	SOC	SON	Sand	Silt	Clay	Db
Coastal Plain			------- g kg^{-1} -------		------------------	% -------------------		Mg m^{-3}
CTO	5.9	6.4	10.17	0.83	70.2	20.3	9.4	1.23
CT	6.1	5.6	9.47	0.67	67.3	23.6	9.1	1.30
NT	5.9	6.0	9.87	0.80	64.7	24.6	10.7	1.50
S	4.8	4.2	10.73	0.83	74.2	17.2	8.6	1.41
Mountain								
CTS	6.1	6.7	8.63	0.73	57.6	20.2	22.1	1.18
	6.3	7.4	9.25	0.80	53.0	23.2	23.8	1.17
NTS	6.0	7.6	11.03	0.95	50.9	26.9	22.2	1.13
NTO	6.9	10.5	15.85	1.48	52.1	26.6	21.3	1.15
CT	5.9	6.9	8.43	0.78	60.8	19.8	19.4	1.32
Piedmont								
NT	5.9	6.0	10.60	0.98	56.9	26.1	17.1	1.41
MBP	5.4	4.6	5.20	0.53	50.7	26.9	22.4	1.31
SCP	6.1	5.9	6.68	0.65	58.1	18.3	23.6	1.25

†Coastal Plain systems/ CT: conventional tillage; NT: no-till; CTO: CT with organic amendments; S: successional vegetation re-growth. Mountain systems/ CT: CT with no inputs; : organic-amended CT system; : synthetic-amended CT system; NTO: organic- amended NT system; NTS: synthetic-amended NT system. Piedmont systems/ : moldboard plow; : spring chisel plow; NT: no-till.
‡CEC: cation exchange capacity (cmol kg^{-1}); SOC (or SON): soil organic C (or N); Db: bulk density.

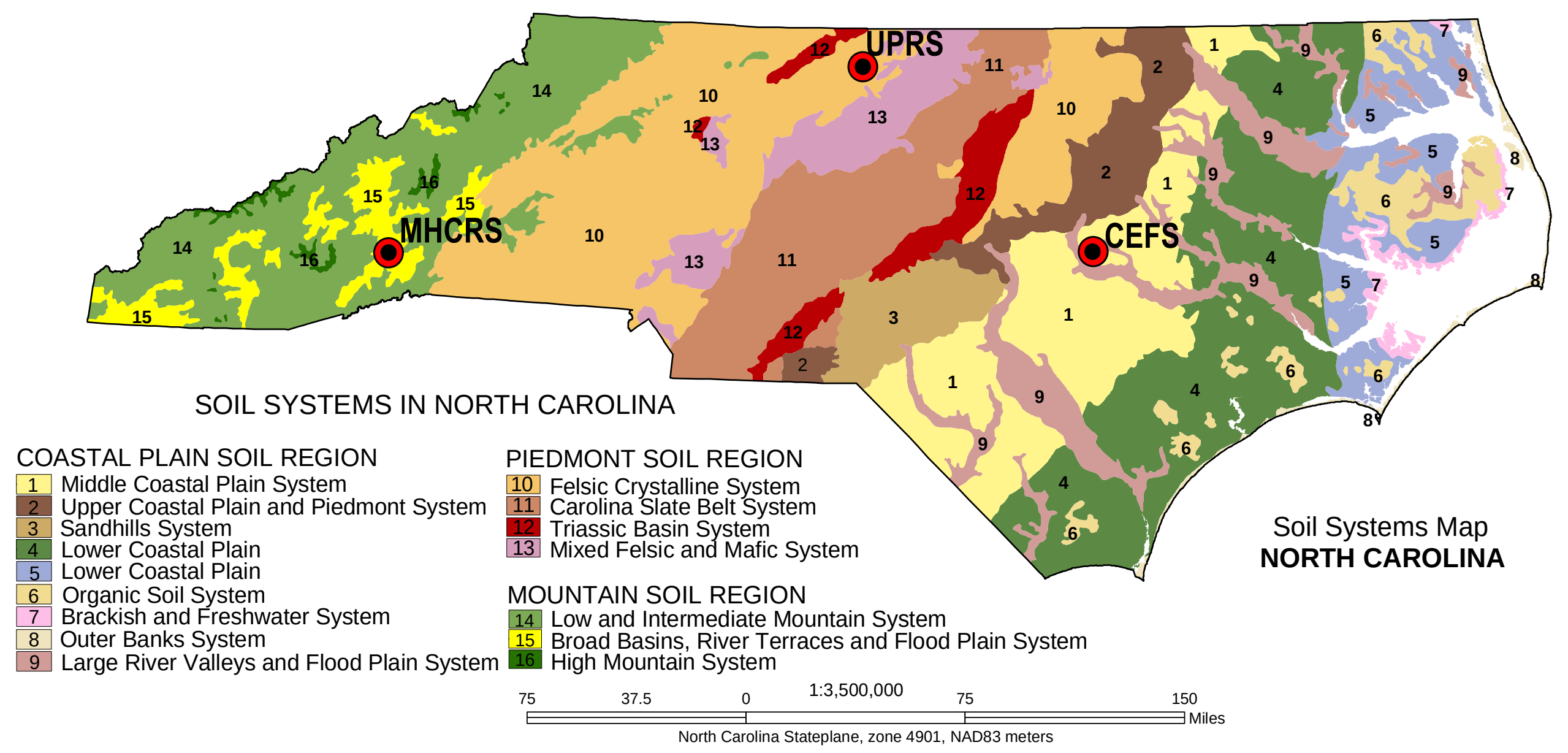

Fig. 1. Soil Regions of North Carolina

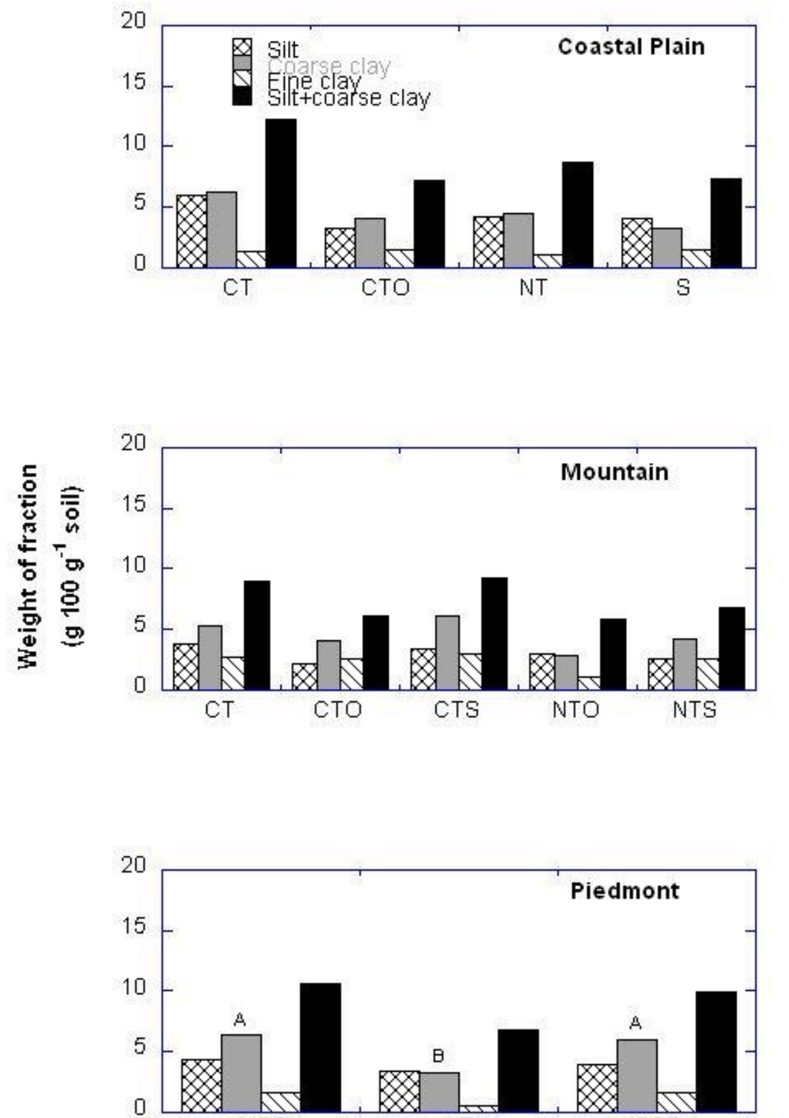

Fig. 2 Particle-size distribution

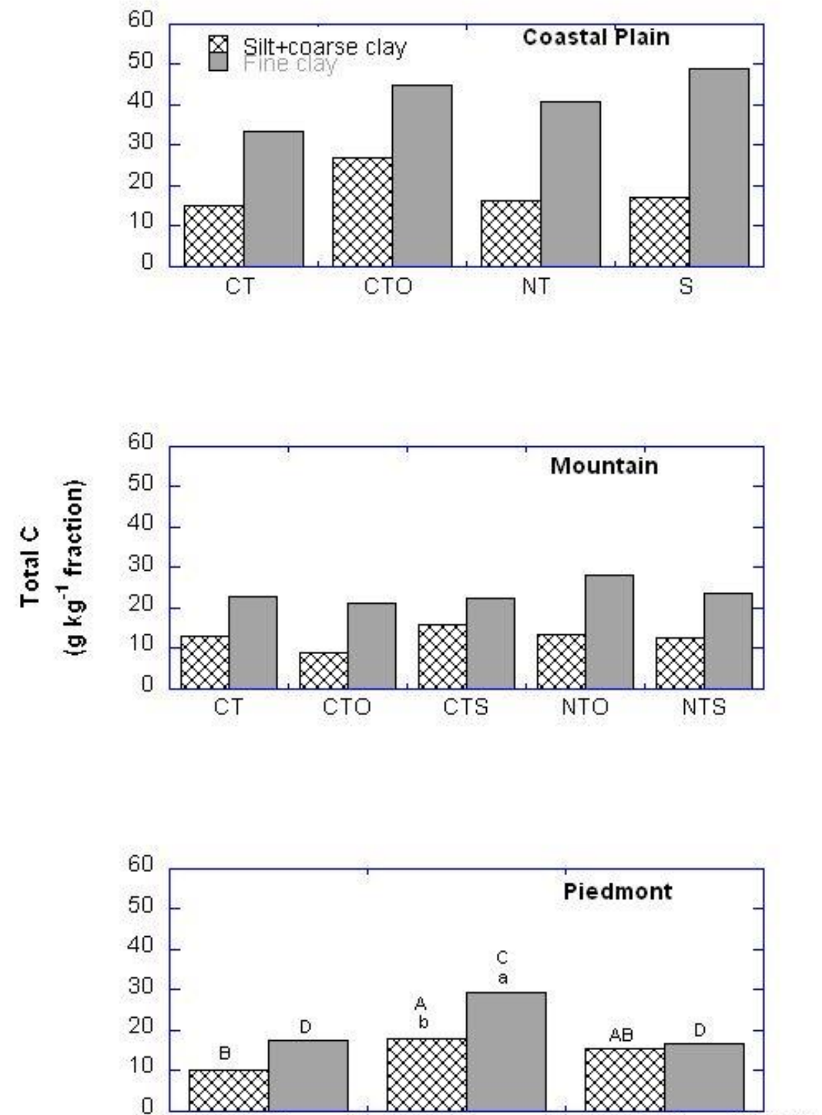

Fig. 3. Organic C distribution in particle-size fractions

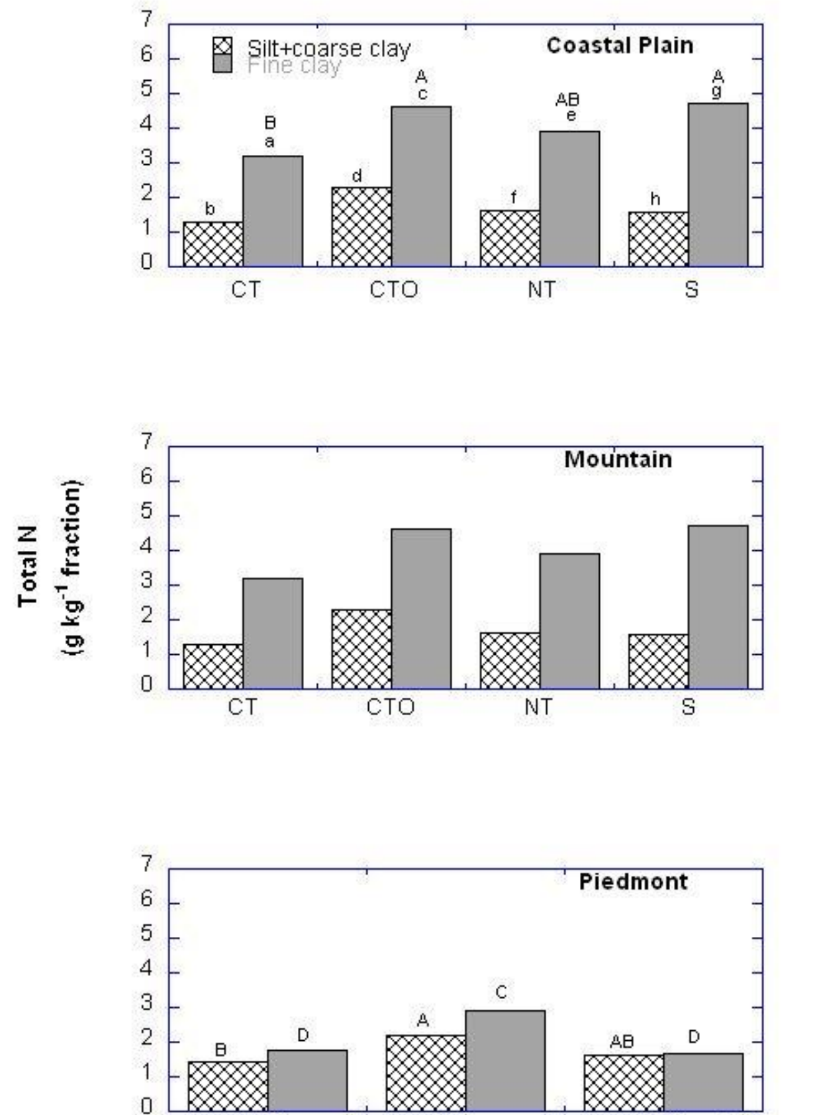

Fig. 4. Organic N distribution in particle-size fractions

Figs. 2-4: Values with similar or no uppercase letters indicate no significant differences between tillage systems; and similar or no lower case letters indicate no significant differences between particle size fractions within tillage systems.

Conclusions

Relative to MBP, NT reduced the coarse clay proportion by half likely by providing cover that prevented surface soil erosion in the Piedmont location over 24 years.

Relative to MBP, NT maintained more C and N in fine or silt+coarse clay. Therefore, NT can potentially increase C sequestration by increasing the C concentration associated with the fine clay fraction.

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